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Preliminary Results on the Decays $\mathbf{D^+} \to K^+\pi^+\pi^-$, $\mathbf{D^+} \to K^+K^+K^-$

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ABSTRACT

Preliminary results on the Doubly Cabibbo Suppressed Decays (DCSD) $D^+ \to K^+\pi^+\pi^-$ and $D^+ \to K^+K^+K^-$ from roughly 40% of the E791 data set are summarized. We present an analysis of candidate events from E791 data in these decay modes. We show that there is a clear signal in the $D^+ \to K^+\pi^+\pi^-$ mode and discuss backgrounds and sources of error in the results. We disagree with a published signal level in the $D^+ \to K^+K^+K^-$ mode.

1. Introduction

Most models for the decay of D-mesons explain the longer D^+ lifetime (relative to the D^0, D_s^+ lifetimes) as being due to interference of the color-allowed and color-suppressed spectator diagrams. This interference only occurs for the D^+ meson, but not for the D^0 and D_s^+ spectator decays. Thus, Doubly Cabibbo Suppressed Decays (DCSD) of the D^+ are interesting both because they are rare and have never been confirmed and because they do not suffer interference in the quark level weak decay spectator diagram. Definite predictions have been made about their rates, based on models of D mesons and their decay mechanisms. Naively, the ratio of the DCSD decay rates to corresponding Cabibbo-favored rates is expected to be of the order of $\tan^4 \theta_C$. The lack of interference in the spectator diagrams further enhances this ratio.

Preliminary analyses of $\sim$40% of E791's data set have now been completed.[1] Since the DCSD signal is expected (and known) to be small compared to the Cabibbo-favored signal, the analysis requires much tighter cuts than those used for the Cabibbo-favored decay $D^+ \to K^-\pi^+\pi^+$. The tighter cuts ensure lower backgrounds. The analysis is further complicated by reflections due to particle misidentification from decays such as $D^+ \to K^-\pi^+\pi^+$ and $D_s^+, D^+ \to K^-K^+\pi^+$. Below, we first describe the cuts used in the analysis and then describe the treatment of the 3-body backgrounds.

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2. Signal selection cuts

Since we are searching for the DCSD signal, we tuned our analysis cuts using the Cabibbo-favored signal. Usually, cuts are chosen to maximize the ratio $S/\sqrt{S+B}$ where S is the signal and B is the background. However, we maximized instead the quantity $5 \times \tan^4 \theta_C \times S/\sqrt{5 \times \tan^4 \theta_C \times S + B}$, (where S and B are the signal and background in the Cabibbo-favored mode) since we naively expected the DCSD signal to be a few times $\tan^4 \theta_C$ of the Cabibbo-favored signal. After this optimization, exactly the same cuts are applied (with one exception discussed below) to the Cabibbo-favored and DCSD samples.

The main cuts can be summarized as follows. All decay tracks are required to travel through at least one magnet, to have a χ^2/DOF less than 5 and a contribution of greater than 25 to the χ^2 if they are forcibly included in the primary vertex fit. The decay vertex is required to be at least 20σ downstream of the production vertex, the p_T-balance around the D flight direction is required to be less than 250 MeV/c, the impact parameter of the D-meson is required to be less than 30 microns at the production vertex, no more than one additional track is allowed within 50 microns of the D decay vertex and the decay vertex is required to be at least 2σ outside any target. Further, the product of the ratios of each decay track's impact parameter to the secondary and primary vertices is required to be less than 0.001.

In the Cabibbo-favored decays, the kaon was identified by charge alone as the particle with charge opposite to that of the D-meson. In the DCSD decays, of the two particles with the same charge as the D-meson the kaon was taken to be the one with larger Čerenkov probability to be a kaon. In both cases however, tracks considered pions are required to have a pion Čerenkov probability greater than 0.55 and similarly the kaon is required to have a kaon probability greater than 0.30. In Figure 1 we show the invariant mass distribution for the Cabibbo-favored decays $D^+ \rightarrow K^- \pi^+ \pi^+$.

3. Treatment of backgrounds

A large number of possible sources of backgrounds were studied. Using Monte Carlo we showed that the background contributions from the decays $\overline{D}^0 \rightarrow K^+ \pi^+ \pi^- \pi^-$, $\overline{D}^0 \rightarrow K^+ \pi^-$, $\overline{D}^0 \rightarrow K^+ \pi^- \pi^0$, $D^+ \rightarrow \pi^+ \pi^- \pi^+$, $D^+ \rightarrow K^- \pi^+ \pi^+ \pi^0$, $D_s^+ \rightarrow \phi e^+ \nu_e$ and $\Lambda_c^+ \rightarrow p K^- \pi^+$ were all negligible. However, the 3-body decays $D^+ \rightarrow K^- \pi^+ \pi^+$ and $D_s^+, D^+ \rightarrow K^- K^+ \pi^+$ contribute significantly to the background. In this analysis we chose to *explicitly cut out* such decays by discarding events which have a candidate $KK\pi$ or Cabibbo-favored $K\pi\pi$ mass in the signal region. Figures 2a and 2b show the candidate DCSD events with the alternate 3-body mass hypotheses just described. It is clear that there is significant contamination. Events that fall in the shaded regions are removed. However, these cuts remove not only the true $K^+ \pi^+ \pi^-$ and $K^+ K^- \pi^+$ decays from D-mesons but also background under those peaks. Hence parts of the "true" (or combinatoric) background under the candidate DCSD signal are also removed.

We have simulated the resulting background shape in three different ways: (1) by mixing D decay tracks from different data events, (2) from Monte Carlo and (3) by fitting the background away from peaks in two-dimensional plots with the DCSD mass on one axis and the reflected mass on the other. All three methods give identical
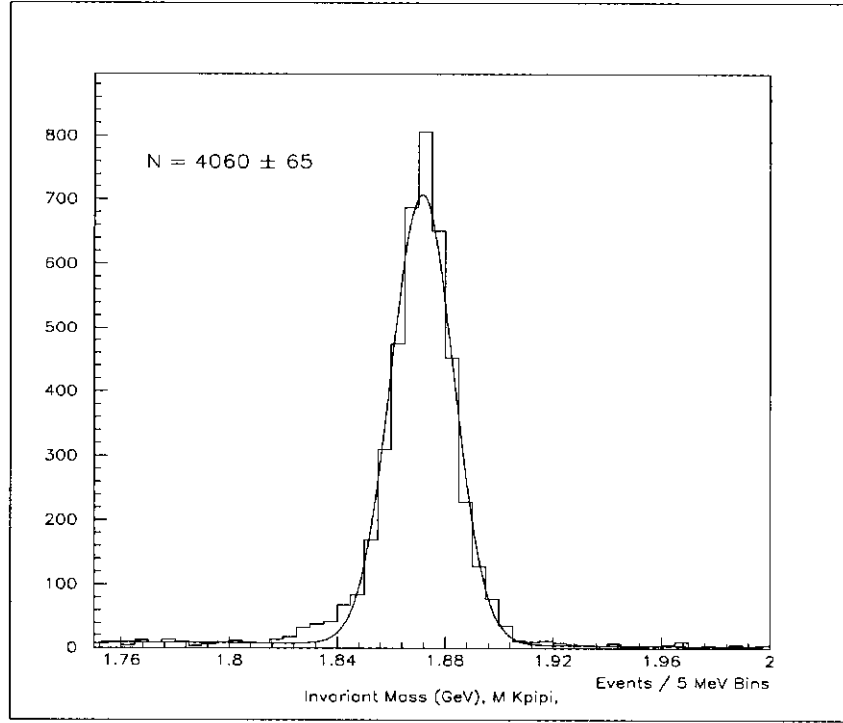
Fig. 1. Invariant mass distribution for the Cabibbo-favored decay $D^+ \to K^-\pi^+\pi^+$ from ~40% of the E791 data sample. This is used as normalization for the doubly Cabibbo-suppressed signal.

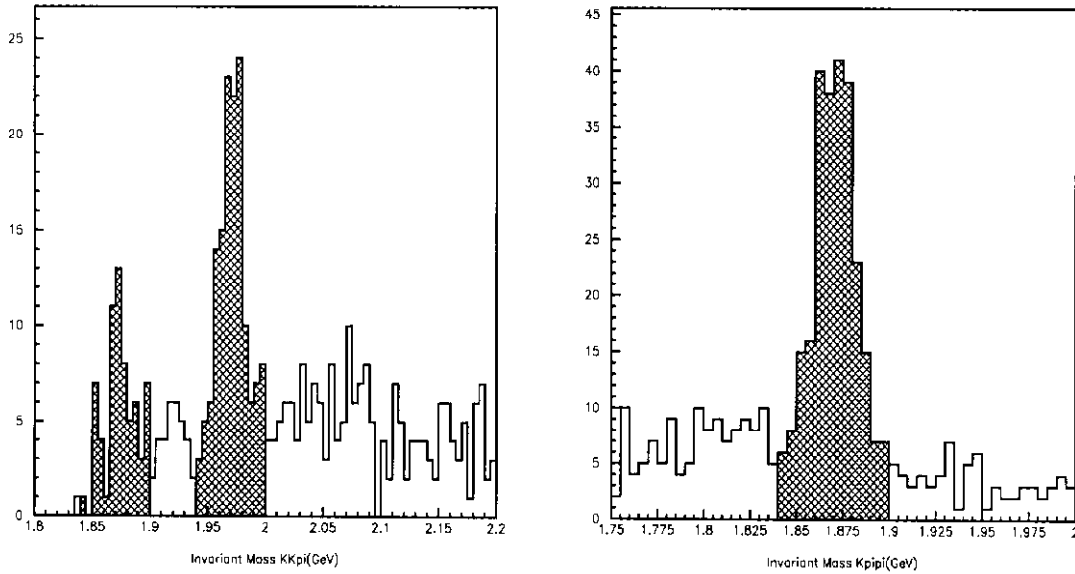Fig. 2. The DCSD candidate events with a) a $K^-K^+\pi^+$ mass hypothesis and b) a $K^-\pi^+\pi^+$ mass hypothesis. Clear reflected signals can be seen in both cases. Events in the shaded regions are explicitly removed from the DCSD sample.

results within errors and we choose the fitting technique to obtain our central values. Figure 3a shows the DCSD invariant mass with the shaded region showing the expected background shape. It is clear that there is a 4σ signal.

4. Results and Systematic errors

From fits to data displayed in the figures above, we obtain the ratio[1]

$$\frac{\Gamma(D^+ \to K^+\pi^-\pi^+)}{\Gamma(D^+ \to K^-\pi^+\pi^+)} = (3.9 \pm 0.9 \pm 0.5) \times \tan^4\theta_c$$

This is already a much better limit/signal than the Particle Data booklet[2] limit of $20 \times \tan^4\theta_c$.

A preliminary examination of the resonant subcomponents has been done and we find that

$$\frac{\Gamma(D^+ \to K^{*0}\pi^+)}{\Gamma(D^+ \to K^-\pi^+\pi^+)} < 2.9 \times \tan^4\theta_c$$

If this is considered to be a signal, we obtain

$$\frac{\Gamma(D^+ \to K^{*0}\pi^+)}{\Gamma(D^+ \to K^-\pi^+\pi^+)} = (1.9 \pm 0.6) \times \tan^4\theta_c$$

(statistical error only). Figure 3b shows the DCSD signal after the K^* selection.

Similarly, an examination of decays to three charged kaons has revealed that

$$\frac{\Gamma(D^+ \to K^+K^-K^+)}{\Gamma(D^+ \to K^-\pi^+\pi^+)} < 1.7 \times \tan^4\theta_c$$

and the resonant decay can be compared to the $\phi\pi^+$ decay mode giving

$$\frac{\Gamma(D^+ \to \phi K^+)}{\Gamma(D^+ \to \phi\pi^+)} < 20.3 \times \tan^4\theta_c$$

These limits are lower than and inconsistent with the level at which WA82 has claimed a signal (in the $K^+K^-K^+$ mode, see[3]) and a little lower than but consistent with a signal observed by E691 (see[4]).

Systematic errors in the above quantities have also been studied. The shift in the central values due to the different background shapes indicates that the systematic error due to the background shape uncertainty is $\sim$10% in the $D^+ \to K^+\pi^+\pi^-$ study and is $\sim$11% in the $D^+ \to K^+K^+K^-$ study. The relative efficiency of the Čerenkov cuts in the DCSD and Cabibbo-favored $D^+ \to K\pi\pi$ analyses is $99.0 \pm 0.2\%$ and we attribute a systematic error of no more than 4% to this source. We have checked that the lifetime of the $D^+ \to K^+\pi^+\pi^-$ sample is consistent with the Cabibbo-favored sample and that the acceptance is uniform across the Dalitz plot.

In the case of the $D^+ \to K^+K^+K^-$ sample, there is some uncertainty in the width of the candidate signal, which contributes an uncertainty of around 3%. Finally, also for the $D^+ \to K^+K^+K^-$ study, the uncertainty in the relative acceptance to the $D^+ \to K^-\pi^+\pi^+$ decays contributes $\sim$5% systematic error and there is a $\sim$5% statistical error due to Monte Carlo statistics.
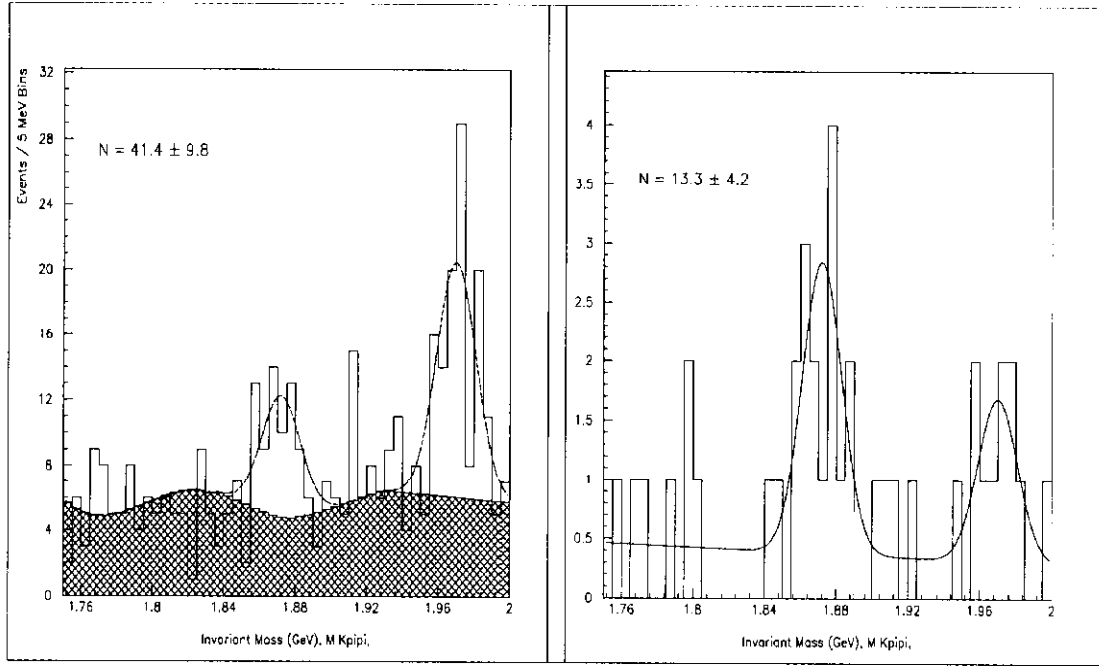
Fig. 3. Invariant mass distributions for a) the doubly Cabibbo-suppressed decay $D^+ \rightarrow K^+\pi^+\pi^-$ and b) for the doubly Cabibbo-suppressed decay $D^+ \rightarrow K^+\pi^+\pi^-$ with the $K\pi$ mass required to lie in the interval 840 - 945 McV/c^2 and the cosine of the angle the Kaon makes with the D-direction in the K^* rest frame required to be greater than 0.5. Both figures are for data from ~40% of the E791 sample.

References

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